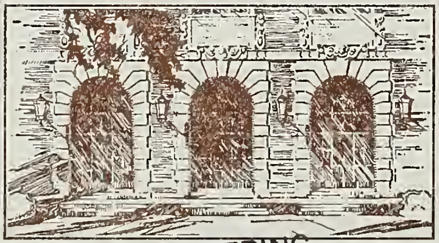

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CAC Document No. 88

LOW SULFUR COAL: A REVISION OF RESERVE AND SUPPLY ESTIMATES

By

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Revised November 30, 1973

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This work was supported by the National Science Foundation, NSF Grant GI 35821.

ABSTRACT

Conventionally, the definition of low sulfur coal, on which traditional reserve and supply estimates are based, depends only on the weight of sulfur in a ton of coal. The Btu content of the coal is not considered. Coal purchases and SO_2 regulations are based on Btu content. A recalculation of reserve estimates of low sulfur coal on a utility average Btu basis reduces traditional U.S. estimates by over 75 percent and Western estimates by almost 85 percent. When calculated on a Btu basis, maximizing low sulfur coal production results in a supply shortage by 1985. The policy implications for an increased dependence on domestic coal include increased cleaning of high sulfur coal and export limitations on low sulfur coal in the short-term. In the mid-term, large capital expenditures in R and D and processes which reduce or eliminate the sulfur content are required. These include stack gas scrubbing, gasification and liquefication. For the consumer, some of these costs can be offset by the elimination of the transportation charge differential between local high sulfur coal and coal from Wyoming, Colorado and Montana.

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SECTION I

SUMMARY

Conventional estimates of both known resources and known recoverable reserves of low sulfur coal are grossly overstated. The current situation is one of serious shortage. High sulfur coal is not in short supply.

A consumer oriented base of 22.6 million Btu/ton, the national electric utility average in 1970, is used to standardize coal reserves and resources on the basis of heat content. This standardization leads to a small increase in the resource/reserve estimates of bituminous coal and to a large reduction in the estimates of subbituminous coal and lignite. It necessarily leads to a reclassification of a significant portion of the U. S. resources and reserves, conventionally considered low sulfur, to higher sulfur categories. Known recoverable reserves in the less than or equal to ($\leq$) 0.7 percent sulfur (weight) category are reduced from a conventional estimate of 68.2 billion tons (De Carlo/Mitre/National Petroleum Council) to 16.4 billion tons on a consistent Btu sulfur adjusted basis. The reduction amounts to 76 percent of the conventional estimate of $\leq$ 0.7 percent sulfur coal and 17 percent of the coal in the 0.8-1.0 percent sulfur category. Conventional recoverable reserve estimates of $\leq$ 0.7 percent sulfur coal in the western states are reduced by almost 85 percent.

The revised estimates are also significant in terms of the future production of low sulfur coal (to 1985). Assuming a maximum annual rate of growth of coal production of 7 percent, cumulative coal production from 1970 through 1985 would, at a maximum, be over 17 billion tons. Because of sulfur limitations required by air pollution control regulations, all production is assigned to the lowest sulfur coal category. Conventional reserve estimates of coal in the $\leq$ 0.7 percent sulfur category indicate that 51.1 billion tons of known recoverable reserves would still be available after 1985. Based on the estimates in this paper, known recoverable reserves of $\leq$ 0.7 percent sulfur coal would fall short of maximum cumulative production by over one billion tons in the same period.

The data revisions are significant for both energy policy planning and air pollution control.

The importance of the distinction between high and low sulfur coal arises because sulfur oxide pollution control regulations prohibit the emission of more than 1.2 pounds of SO_2 per million Btu's of heat generated by the burning of coal in new plants. To meet this standard, a coal containing 24 million Btu/ton cannot contain more than 0.7 percent sulfur by weight. Coals with a lower heat value must contain correspondingly less sulfur if they are to meet the standard.

Conventional estimates of resources and reserves (De Carlo/Mitre/ National Petroleum Council) are based on the simple addition of coal tonnages, without regard to heat content. However, to the consumer, such as an electric utility, what is important is the heat content, expressed as the number of Btu's per pound or per ton, in the fuel. The consumer knows that to produce a given amount of heat, a coal with a heat content of 18 million Btu/ton is worth only three-fourths as much as one containing 24 million Btu/ton. Alternatively, to produce the same amount of heat, he would have to use significantly larger amounts of low Btu coal than of high Btu coal. Accordingly, if he owned a mine of each, and the stated reserves of both were equal, he would value the reserve of one at only three-fourths as much as the other. Unfortunately, in consuming the additional tonnage of low Btu coal to make up the Btu differential, the sulfur content of the additional tonnage is also emitted. Therefore, the amount of sulfur in the additional tonnage must be included to determine a comparable sulfur content for both coals. Assuming that both coals contained 0.7 percent sulfur (by weight) on a simple or conventional tonnage basis, only the 24 million Btu/ton coal would meet air pollution control standards. The 18 million Btu/ton coal would be rated by the consumer as if it contained 0.93 percent sulfur (0.7 times 24 divided by 18). This is the equivalent of shifting the lower Btu coal out of the $\leq$ 0.7 percent sulfur category and into the 0.8-1.0 percent sulfur class. The consumer, owning both mines, would value the coals according to their "effective" sulfur content.

In this study, Section II A compares several current alternative measures of coal resources and reserves. Although these vary considerably, the estimates are shown to depend on the definitions used for the data collection.

Section II B presents both the conventional methodology and that used in this paper to estimate low sulfur coal resources and reserves. The results have been cited above. Based on a study made for the Bureau of Mines, the addition to the resource/reserve base, made possible by washing to remove sulfur, is estimated. This is an attempt to determine what increase in the disappointingly low estimates developed in this study can be made by assuming the generalized use of a current coal preparation technique. It is found that if some very optimistic assumptions are made, the overstatement of conventional resource/reserve estimates of low sulfur coal is only 33 percent. More probable assumptions lead to the conclusion that, even with washing, the overstatement is about 67 percent.

Following an analysis of the production of low sulfur coal (Section III), the results of which are cited above, the relationship between coal prices and reserve/resource estimates is developed in Section IV. This section also deals with the effect of mine safety and stripmining legislation on coal production and reserve estimates.

Based on current technology and market conditions the analysis in Section V suggests a number of offsetting policy options. For the short-run of one to five years, end use controls are shown to provide a limited amount of low sulfur coal for the electric utility and industrial sectors. The restriction of exports of low sulfur coal could provide about 55-60 million tons for the domestic market in the coming year. Sales of low sulfur coal on the open market from captive mines (those owned by the consuming firms), would depend on the rate at which current output capacity could be increased.

Long-run policy alternatives necessarily involve the expanded use of high sulfur coal. This can be accomplished most easily by the reduction of air quality standards. Alternatively, efforts leading to the improvement and implementation of coal gasification, coal liquefication and stack gas scrubbing can be advanced. These last require the additional use of coal; there is a fuel penalty for all of them, but it is least for scrubbing. The data suggest that at current prices for alternative domestic and foreign fuels and the current premium paid for low sulfur fuels, that all three processes may be profitable. Additionally, it is found that if a scrubber is only 75 percent efficient

it can handle the average sulfur content (2.5 percent) of utility coals. If it is only 75 percent reliable, on a new steam plant, the joint availability of the scrubber and the plant equals the output availability of nuclear power plants.

Given the transportation costs of western coal to the midwest, the last three alternatives, all based on indigenous midwestern high sulfur coal, are probably cheaper than western coal burned in the midwest to meet air quality standards. Given the water resources of the Rocky Mountain area it is also probable that more sites for coal gasification and liquefication plants can be found in the midwest than in the far west.

SECTION II

RESERVE ESTIMATES

A. Coal Resources and Reserves

1. Definitions

There are many different coal "reserve" estimates. While the figures produced vary widely, they are not necessarily inconsistent. The differences are based primarily on the expected use of the data which predicates the bases on which the data are collected. It is important, however, to be aware of some of the distinctions. Of principal interest here, is the difference between resources in the sense of mere physical existence and that portion of these resources that can be recovered economically at current prices with existing technology. These are called economically recoverable reserves. Both measures are stated in terms of tons, however, the difference between them is significant for policy purposes as only the latter are available for consumption in the present and near future. The former may become available after a longer period of time or may never be recovered.

The estimate of coal resources in the broadest physical sense is the resource base.(1) An examination of those coal mining areas which have been mapped and explored yields a resource estimate of 1.56 trillion tons. Even this is limited because not all areas have been thoroughly mapped and the estimate includes only those resources with less than a 3000 foot overburden. This estimate is further subdivided into measured, indicated and inferred classes based on the reliability of the estimate. Inferred resource measures are based on geologic evidence alone. Measures of indicated resources are derived from both specific observations and geologic projections based on these observations. Measured resources, properly called physical reserves to distinguish them from economically recoverable reserves, are the most reliable estimates. These are based on data derived from outcroppings, trenches, mine workings and closely spaced drill holes. In effect, it is information obtained from existing coal seams.

Because of the limits to existing coal mining technology resource estimates may be further limited to those lying beneath less than 1000 feet of overburden. These are further subdivided into thick, intermediate and thin coal seams. High rank coals, those with a high heat content such as anthracite, semianthracite and bituminous coal, are recorded as lying in thick seams if the seam is more than 42 inches thick. Low rank coals, such as subbituminous coal and lignite are classified in thick seams only if the seam is greater than 10 feet thick. Intermediate seams are 28-42 inches and 5-10 feet for high rank and low rank coals, respectively. Thin seams include only those from 14-28 inches or 2.5-5 feet thick. It may be noted that by restricting the depth of the overburden and classifying by seam thicknesses which differ by coal rank, a concept of economic classification is introduced. This, however, is only implicit and is not meant to indicate economically recoverable reserves.

2. Estimates

Measured and indicated coal resources covered by less than 1000 feet of overburden, lying in beds of all three thicknesses, amounted to 483.6 billion tons in 1970. Of this, 124.8 billion tons were classified as measured reserves. Alternatively, measured reserves and indicated resources lying in thick and intermediate beds or seams totaled 394.1 billion tons. Of this, 349.1 billion tons was mineable by underground methods. By eliminating the more expensively mined bituminous and subbituminous coal and lignite in beds of intermediate thickness, this total can be reduced to a physical reserve estimate of 209.2 billion tons. Assuming that 50 percent of this can be recovered at current prices by current mining techniques we have an estimate of 104.6 billion tons of economically recoverable reserves underground. To this last can be added 45 billion tons of economically recoverable reserves accessible almost exclusively by stripmining.

The U.S. Geological Survey estimates identified recoverable coal resources in the United States at 200 billion tons lying in thick beds. At a somewhat higher cost of recovery an additional 190 billion tons can be added by including coal in beds of intermediate thickness. Estimates of identified submarginal resources, stated in

terms of weight but essentially meaning those which cannot be economically recovered at prices less than approximately 1.5 times current prices and/or with current mining techniques, are an additional 1200 billion tons. Finally, undiscovered coal resources, with an overburden of less than 3000 feet, are estimated to be an additional 1300 billion tons. A recovery factor of 50 percent of the coal in place is assumed.(2) The Bureau of Mines estimates coal resources in the United States, of all ranks, as of January 1, 1970, at 778,274 million short tons. This assumes a 50 percent recovery of the coal in place.(3) It is approximately one-half of the 1.56 trillion tons noted above but it is not a measure of economically recoverable reserves.

Table 1 indicates three additional estimates of coal and lignite reserves in the United States. The estimate by the Department of the Interior,(4) while it is reported to be recoverable reserves, is actually similar to the Bureau of Mines' estimate of coal resources noted above. As a test of this, it can be seen that the inclusion of Alaska and the doubling of the total yields approximately 1.157 trillion tons. This is certainly too close to the U.S. Geological Survey resource estimate of 1.56 trillion tons, cited above, for the figures in Table 1 (column 1) to be considered recoverable reserves. It is, in fact, merely another physical resource estimate. The two estimates from the Mitre Corporation study(5) are somewhat different. Known reserves (column 2) are in the context of the Bureau of Mines' estimates and include both known recoverable reserves and known marginal and submarginal resources. This is therefore a resource estimate. Column 3 represents a considerable effort to reduce the estimate of column 2 from a resource base to one of known recoverable reserves alone. The result is comparable with the 209.2 billion tons reported by the National Petroleum Council. In contrast, Hubert Risser(6) estimated that at the end of 1970, about 390 billion tons of coal were considered mineable with current technology, of which 200 billion tons could be produced at current costs and 190 billion tons at somewhat higher costs. If Risser's estimate of economically recoverable reserves is accepted, both the Mitre (192.6BT) and the

Table 1

Bituminous Coal and Lignite Reserves
Comparative Estimates
(Million Tons)

	Department of the Interior(1)	Mitre Corporation(2) Known(3)	Recoverable(4)
Appalachia	109581	216440	25875
Interior	178318	372627	72943
Rocky Mountains	228358	872445	94265
West Coast (ex. Alaska)	2617	5950	530
Total	518874	1467462	193613

(1) Department of the Interior, United States Energy Fact Sheets by States and Regions, February 1973. Measured coal reserves (1/1/71) that are economically recoverable. The underground coal recovery factor is estimated to be 57 percent, the area stripmining recovery factor is 90 percent, and the contour stripmining recovery factor is estimated at 80 percent. (page 3).

(2) L. Hoffman, Survey of Coal Availabilities by Sulfur Content, Report to the Environmental Protection Agency, The Mitre Corporation, MTR-6086, May 1972.

(3) Known reserves: recoverable, marginal and submarginal based on U.S. Geological Survey classifications.

(4) First order estimate of known recoverable reserves alone. U.S. Geological Survey classification is the basis. Recovery factors are: underground mines, 50 percent; stripmining in Appalachia and Interior regions, 60 percent; stripmining in the Rocky Mountains region, 80 percent. (page 15).

National Petroleum Council estimates (149.6 BT) can also be considered economically recoverable reserves. If, however, the National Petroleum Council estimate is accepted, both the Mitre and Risser estimates may include elements of coal, unrecoverable at current prices.

As this paper is concerned primarily with reserve data in terms of the sulfur content of the coal, the Mitre estimates of recoverable reserves will be used. These are significantly less than any of the resource estimates mentioned above. This is not unimportant. Given the proper conditions of price and technology, resources tend to become reserves. It is also important to note that even the estimates of known recoverable reserves are large with respect to national energy needs to the turn of the century. Therefore, the question of falling short of energy (as opposed to a temporary fuel shortage) in the intermediate future, or until other forms of energy can be developed and utilized, is not critical. Properly used, coal can provide a very effective cushion for U.S. energy demands.

B. Low Sulfur Coal

The amount of sulfur in coal began to be important following the passage of the Clean Air Act.(7) As a result of this, and succeeding amendments, a limit of 1.2 pounds of sulfur oxide emissions per million Btu's of heat generated was set. Until this winter, it was widely expected that this permissible limit would be lowered. At the 1.2 pound SO_2 emission limit a coal containing 24 million Btu's cannot contain more than 0.7 percent sulfur and still meet the standard. The result has been a premium price for even nonmetallurgical coals containing 0.7 percent sulfur or less, a shift to other fuels, and some movement towards advancing stack gas scrubbing, coal gasification and coal liquefication.

While recoverable reserves of coal are adequate to our needs, this is not true with respect to coal with a sulfur content of $\leq$ 0.7 percent. As conventionally estimated, using current combustion technology, little U.S. bituminous coal can meet a 1.2 pounds SO_2/million Btu emission standard, still less a 1.0 pound SO_2 standard. As the 0.7 pound SO_2 emission standard is approached, a 12,000 Btu/pound coal could not contain more than about 0.4 percent sulfur by weight in the coal itself. There is very little bituminous coal in the United States that

can meet such a standard.

Of equal or greater importance is the overstatement, in conventional estimates, of low sulfur coal in the $\leq$ 0.7 percent sulfur in the fuel category. The same is true of the next class, normally regarded as 0.8 to 1.0 percent sulfur by weight in coal. These overstatements occur because in the basic data estimates of tons of coal of different Btu content are simply added within sulfur classes rather than adjusted for the fact that the consumer of the coal must compare the fuel that he uses in terms of the Btu output that he gets. Therefore, proper summation of resources requires that adjustments be made. In the course of these adjustments not only are the reserve estimates altered to take into account the Btu content of the reserve, but the sulfur content classification shifts. The published estimates of the Department of the Interior and the Bureau of Mines do not appear to treat these problems. The National Petroleum Council notes that of the estimates of known coal resources, mapped and explored, and lying under less than 3000 feet of overburden, 46 percent are $\leq$ 0.7 percent sulfur coal. This amounts to 720 billion tons.[(8)] They further state that "... the bulk of western coal reserves have sulfur contents between 0.5 and 1.0 percent and substantial tonnages are currently burned in areas where 1.0-percent sulfur is presently considered an acceptable fuel, particularly in the West Central region."[(9)] Unfortunately, the Mitre Corporation study does not treat this problem either.[(10)] While it is true that one can, in a sense, separate the change in total reserves due to putting them on a constant Btu basis from the shift in sulfur classification, this is more apparent than real. The two are, in fact, interrelated.

1. Resources and Reserves

Table 2 is a corrected version of the Mitre Corporation estimates of resources and recoverable reserves as of January 1, 1965. It is reproduced in a slightly different format. In the Mitre table, the figures for known reserves come from DeCarlo.[(11)] The estimates of known recoverable reserves are derived by the Mitre Corporation. It should be noted that the sulfur content classifications are those of DeCarlo. Because, to date, this is the only source which lists coal reserves with respect to such a fine breakdown in terms of sulfur

content, it is the one that is analyzed here. Even the original classifications may be somewhat misstated. DeCarlo points that "... in most instances, the analyses used were those of cleaned coals. In low sulfur coals these sulfur levels would not be significantly different from the raw coal, but for the medium and high sulfur coals, the raw coal may range from .5 to 1.0 percent higher in sulfur."(12)

Without going further in the analysis of the placement of reserve tonnages in individual sulfur content categories it is possible, looking at Table 2 to suggest that a casual addition of all coals in the $\leq$ 0.7 percent sulfur content by weight category is not warranted. Known recoverable reserves of lignite in this category amount to almost 56 percent of the entire reserve of all ranks in this sulfur category. However, problems exist in the use of lignite by steam electric power plants such that currently this may be considered more a potential than an actual reserve.(13) Lignite can be used in a new plant especially designed for the purpose. Some mine mouth power plants burning lignite have been built. However, an existing plant, designed for a high Btu bituminous coal, would have to be redesigned. The use of lignite in such a plant implies an input of about twice as much fuel and an output of about four times as much ash. Typically the facility is not equipped to handle this. On the other hand, the inclusion of anthracite coal in the totals also depends largely on its acceptance by utilities. There is evidence that it can be used, if only for blending.(14)

Table 3 is an estimate of known resources and known recoverable reserves, categorized by sulfur content, with all coal estimated on a comparable Btu basis and the sulfur categories into which the reserves are placed adjusted because of the new Btu basis. The argument for this is as follows: To a consumer, such as an electric utility, what is important is the Btu content of the fuel. Therefore, a low Btu content fuel, such as lignite, if it is to produce the same amount of heat as a high Btu fuel, such as a typical Illinois coal, would require the purchase of significantly larger amounts of lignite. Alternatively stated, to the consumer, the value of a lignite reserve, on a Btu basis, is significantly less than the amount indicated by the crude number of tons of lignite shown in Table 2. Unfortunately, in consuming the

Table 2

United States Coal: Resources and Recoverable Reserves (Jan. 1, 1965)
(10^6 Short Tons)

Bituminous Coal	Sulfur Content[1] ≤ 0.7	0.8-1.0	1.1-1.5	1.6-2.0	2.1-2.5	2.6-3.0	3.1-3.5	3.6-4.0	>4.0	Total
Appalachian, North	45 (2)	2755	21370	23050	27525	11950	8780	7155	800	103430
	5 (3)	360	2780	2995	3580	1550	1140	930	105	13445
South	37275	41025	18135	9890	2770	3510	275	45	85	113010
	4100	4510	1995	1090	305	385	30	5	10	12430
Total	37320	43780	39505	32940	30295	15460	9055	7200	885	216440
	4105	4870	4775	4085	3885	1935	1170	935	115	25875
Interior, East[4]	195	781	6941	6520	7770	33588	69679	91233	37006	253712
	50	195	1735	1630	1942	8397	17420	22808	9252	63428
West	250	770	2475	1180	9170	2070	11340	28975	62685	118915
	20	60	200	95	735	165	905	2320	5015	9515
Total	445	1551	9416	7700	16940	35658	81019	120208	99691	372627
	70	255	1935	1725	2677	8562	18325	25128	14267	72943
Rockies, North	6275	6815	205	395	400	175	40	25	590	14920
	690	750	20	45	45	20	5	0	65	1640
South	38940	56295	-	1525	-	-	-	-	3995	100755
	3895	5630	-	150	-	-	-	-	400	10075
Total	45215	63110	205	1920	400	175	40	25	4585	115675
	4585	6380	20	215	45	20	5	0	465	11715
West Coast[5]	900	685	-	-	-	-	-	-	-	1585
	80	60	-	-	-	-	-	-	-	140
Bituminous Coal-Total	83880	109126	49126	42560	47635	51293	90114	127433	105161	706327
	8840	11565	6730	6025	6607	10517	19500	26063	14847	110673

Subbituminous Coal										
Rockies, North	129665	109045	-	1300	-	-	-	-	10	240020
	14265	11995	-	145	-	-	-	-	-	26405
South	52005	16910	150	-	-	-	-	-	-	69115
	5205	1690	15	-	-	-	-	-	-	6910
Total	181670	125955	150	1300	-	-	-	-	10	309135
	19470	13685	15	145	-	-	-	-	-	33315
West Coast(5)	3780	585	-	-	-	-	-	-	-	4365
	340	50	-	-	-	-	-	-	-	390
Subbituminous Coal-Total	185450	126580	150	1300	-	-	-	-	10	313500
	19810	13735	15	145	-	-	-	-	-	33705
Lignite (>98% N. Rockies)	344620	61385	41165	-	-	465	-	-	-	447635
	37905	6750	4530	-	-	50	-	-	-	49235
Anthracite (>95% Pa.)	12550	95	-	145	285	-	-	-	-	13075
	1630	10	-	20	35	-	-	-	-	1695
Total-All Ranks	626500	297186	90441	44005	47920	51758	90114	127433	105171	1480537
	68185	32060	11275	6190	6642	10567	19500	26063	14847	195308

Source: L. Hoffman, et al, Survey of Coal Availabilities by Sulfur Content, Final Report, the Mitre Corporation, for the Environmental Protection Agency, MTR-6086, (May 1972), Table XVI, p. 22.

(1) Sulfur content is in percent by weight on a dry basis.

(2) The larger number on each line refers to known resources. This includes both known recoverable reserves and known marginal and sub-marginal resources. It does not include estimates of undiscovered resources.

(3) The smaller number on each line is the Mitre estimate of known recoverable reserves alone; that which can be recovered with present technology and current prices.

(4) Eastern Interior is corrected. Mitre figures are based on J.A. De Carlo, et al, Sulfur Content of United States Coals, Bureau of Mines, IC 8312, (1966), Table A-1, p. 19. This was altered by a revision for the Illinois data in which the reserve estimates for low sulfur coal were modified. See, U.S. Department of Health Education and Welfare, Control Techniques for Sulfur Oxide Air Pollutants, NAPCA No. AP-52, (January 1969), Table 4-2, page 4-11.

(5) Excluding Alaska.

Regions: Northern Appalachia is defined as Pennsylvania, the northern part of West Virginia and Maryland. The southern Appalachian region is composed of eastern Kentucky, the southern part of West Virginia, Tennessee, Virginia and Alabama. The eastern Interior region is made up of Illinois, Indiana, western Kentucky, and Ohio. The western Interior region is composed of Iowa, Kansas, Missouri, Oklahoma, Arkansas, and Texas. The northern Rocky Mountains region is made up of North and South Dakota, Montana, Wyoming, and Idaho. The sourthern Rock Mountains region comprises Colorado, Utah, Arizona, and New Mexico. Finally, the West Coast includes Washington, Oregon, and California; it excludes Alaska.

Table 3

United States Low Sulfur Coal: Resources and
Recoverable Reserves (Jan. 1, 1965), Comparable
Btu and Effective Sulfur Basis
(10^6 Short Tons)

	Sulfur Content			
	≤ 0.7	0.8-1.0	1.1-1.5	1.6-2.0
Bituminous Coal				
Appalachian, North	54	3306	53304	33030
	6	432	6930	4296
South	44730	49230	33630	3324
	4920	5412	3702	3666
Total	44784	52536	86934	36354
	4926	5844	10632	4662
Interior, East	207	828	7357	6911
	53	207	1839	1728
West	265	801	2574	1227
	21	62	208	99
Total	472	1629	9931	8138
	74	269	2047	1827
Rockies, North	6526	7088	213	411
	718	780	21	47
South	42055	60799	-	1647
	4207	6080	-	162
Total	48581	67887	213	2058
	4925	6860	21	209
West Coast	855	651	-	-
	76	57	-	-
Bituminous Coal-Total	94692	122703	97078	46550
	10001	13030	12700	6698
Subbituminous Coal				
Rockies, North	-	107622	90507	-
	-	11840	9956	-
South	46329	15050	133	-
	4632	1504	13	-
Total	46329	122672	90640	-
	4632	13344	9969	-
West Coast	-	3754	-	-
	-	335	-	-
Subbituminous Coal-Total	46329	126426	90640	-
	4632	13679	9969	-
Lignite	-	-	243603	-
	-	-	26793	-
Anthracite	14056	106	-	162
	1826	11	-	22
Total-All Ranks	155077	249235	431321	46712
	16459	26720	49462	6720

Source: Tables 4 and 5

additional amount of lignite to make up the Btu differential, the sulfur content of the additional tonnage is also emitted. Therefore, the amount of sulfur in the additional amount of lignite burned to make up the Btu differential must be included to arrive at a comparable sulfur percentage for lignite. In short, its effective sulfur content has been increased. Table 3 shows the results of such a reclassification. Tables 4 and 5 indicate the intermediate steps in the calculation of this reclassification.

A comparison of Tables 2 and 3 indicates that the total of all ranks of coal in the $\leq$ 0.7 percent sulfur content category are, due to the reclassification, reduced by almost 76 percent.(15) Furthermore, the reclassification reduces the reserves of coal in the succeeding class, 0.8 to 1.0 percent sulfur, by almost 17 percent. Comparing Tables 2 and 3 on a regional basis, it can be seen that known recoverable reserves in the east (defined as the Appalachian and Interior regions) increase by almost 18 percent. This is due primarily to a reevaluation of reserves based on Btu content. In the west (defined as the Rockies and the West Coast excluding Alaska), however, there is an almost 85 percent decrease in the reserves of low sulfur coal in the $\leq$ 0.7 percent sulfur category. While it is true that most of the coal removed from the low sulfur categories is reassigned into higher sulfur categories, absent stack gas cleaning equipment and coal gasification or liquefication, because of air pollution control regulations these coals are not further considered here.

Tables 4 and 5 provide the basis for the development of Table 3. Table 4 shows the conversion of Table 2 to a comparable Btu basis. The standard used for the tonnage conversion was 22.6 million Btu's/short ton. This is based on an estimate made by the Department of Interior of the average Btu content of coals used for electric power generation in 1970.(16) It should be noted that the heat content of these coals has been declining over the past few years. Electric power generation was selected simply because it is the primary use for American coal. The results are sensitive to the assumed base; this may be ascertained by using a different Btu standard. The Bureau of Mines estimates that the average U.S. coal consumed contained 12,010 Btu/pound in 1971. This excludes metallurgical and export coals.(17) The tonnage

Table 4

United States Coal: Resources and Recoverable Reserves (Jan. 1, 1965)
Comparable Btu Basis
(10^6 Short Tons)
Sulfur Content

	MM Btu/T[1]	Tonnage[2] Conversion	≤0.7	0.8-1.0	1.1-1.5	1.6-2.0	2.1-2.5	>2.5
Bituminous Coal								
Appalachian, North			54	3306	25644	27660	33030	34422
	27.0	1.20	6	432	3336	3594	4296	4470
South			44730	49230	21762	11868	3324	4698
	27.2	1.20	4920	5412	2394	1308	366	516
Total			44784	52536	47406	39628	36354	39120
			4926	5844	5730	4902	4662	4986
Interior, East			207	828	7357	6911	8236	245395
	24.0	1.06	53	207	1839	1728	2058	61348
West			265	801	2574	1227	9537	109268
	23.5	1.04	21	62	208	99	764	8742
Total			472	1629	9931	8138	17773	354663
			74	269	2047	1827	2822	70090
Rockies, North			6526	7088	213	411	416	863
	23.4	1.04	718	780	21	47	47	93
South			42055	60799	-	1647	-	4314
	24.4	1.08	4207	6080	-	162	-	432
Total			48581	67887	213	2058	416	5177
			4925	6860	21	209	47	525
West Coast			855	651	-	-	-	-
	21.4	.95	76	57	-	-	-	-
Bituminous Coal-Total			94692	122703	57550	49824	54543	398960
	-	-	10001	13030	7798	6938	7531	75601

Subbituminous Coal								
Rockies, North			107622	90507	-	1079	-	9
	18.8	.83	11840	9956	-	120	-	-
South			46329	15050	133	-	-	-
	20.2	.89	4632	1504	13	-	-	-
West Coast			3251	503	-	-	-	-
	[19.5]	[.86]	292	43	-	-	-	-
Subbituminous Coal-Total			157202	106060	133	1079	-	9
	-	-	16764	11503	13	120	-	-
Lignite								
Rocky Mountain			206772	36831	24699	-	-	329
	13.5	.60	22743	4050	2718	-	-	30
Anthracite								
North Appalachian			14056	106	-	162	319	-
	25.4	1.12	1826	11	-	22	39	-
Total-All Ranks			472722	265700	82382	51065	54862	399298
	-	-	51334	28594	10529	7080	7570	75631

Source: Table 2

(1) Weighted average Btu values as received for steam coals in each region. Bituminous and subbituminous: Hoffman, op. cit., Appendix II, (West Coast subbituminous is the simple average of northern and sourthern Rocky Mountain regions). Lignite: Hoffman, op. cit., page 6. Anthracite: Department of the Interior, United States Energy Fact Sheets, 1971, (February 1973), p. 4.

(2) Tonnage conversion based on 22.6 MM Btu/short ton for electric generation. Department of the Interior, op. cit., p. 4.

Table 5

United States Coal: Resources and Recoverable Reserves (Jan. 1, 1965), Effective Sulfur Basis

(10^6 Short Tons)
Sulfur Content(1)

	≤0.749 (0.65)	0.750-1.049 (0.90)	1.05-1.549 (1.3)	1.55-2.049 (1.8)
Bituminous Coal				
Appalachian, North	45 5 (.54)	2755 360 (.75)	44420 5775 (1.3)(2)	27525 3580 (1.92)
South	37275 4100 (.54)	41025 4510 (.75)	28025 3085 (1.2)(3)	2770 305 (1.92)
Total	37320 4105	43780 4870	72445 8860	30295 3885
Interior, East	195 50 (.61)	781 195 (.85)	6941 1735 (1.23)	6520 1630 (1.70)
West	250 20 (.62)	770 60 (.87)	2475 200 (1.25)	1180 95 (1.73)
Total	445 70	1551 255	9416 1935	7700 1725
Rockies, North	6275 690 (.62)	6815 750 (.86)	205 20 (1.24)	395 42 (1.72)
South	38940 3895 (.60)	56295 5630 (.83)	- -	1525 150 (1.67)
Total	45215 4585	63110 6380	205 20	1920 192
West Coast	900 80 (.68)	685 60 (.95)	- -	- -
Bituminous Coal-Total	83880 8840	109126 11565	82066 10815	39915 5802
Subbituminous Coal				
Rockies, North	- -	129665 14265 (.78)	109045 11995 (1.08)	- -
South	52055 5205 (.73)	16910 1690 (1.01)	150 15 (1.5)	- -
Total	52055 5205	146575 15955	109195 12010	- -
West Coast	- -	4365 390 (.92)(4)	- -	- -
Subbituminous Coal	52055 5205	150940 16345	109195 12010	- -
Lignite	- -	- -	406005 44655 (1.14)(5)	- -
Anthracite	12550 1630 (.58)	95 10 (.82)	- -	145 20 (1.64)
Total-All Ranks	148485 15675	26016 27920	597266 67480	40060 5822

Source: Based on Table 4

(1) To avoid the rounded range gaps found in De Carlo and succeeding publications (i.e. 1.0-1.1), differences have been halved to eliminate the gap. Figures in parentheses are the mid point of the ranges with the exception of the first (0.65) which was assumed for computational purposes. In the body of the table, figures in the parentheses refer to the implied average sulfur level of the tonnages in each class.

(2) Weighted average of 21,370 known reserves and 2780 known recoverable reserves at 1.08 percent plus 23050 known reserves and 2995 known recoverable reserves at 1.50 percent.

(3) Weighted average of 18135 known reserves and 1995 known recoverable reserves at 1.08 percent plus 9890 known reserves and 1090 known recoverable reserves at 1.50 percent.

(4) Weighted average of 3780 known reserves and 340 known recoverable reserves at 0.76 percent plus 585 known reserves and 50 known recoverable reserves at 1.05 percent.

(5) Weighted average of 344620 known reserves and 37905 known recoverable reserves at 1.08 percent plus 61385 known reserves and 6750 known recoverable reserves at 1.5 percent.

conversion figures in column 2 of Table 4 are simply the ratio of the weighted average Btu's per ton found in column 1 to the standard 22.6 million Btu's per ton. The tonnage conversion factor for each region was then applied to the figures found in Table 2.

Table 5 repeats the tonnage figures found in Table 2. However, where necessary, these tonnage figures are reclassified by sulfur content. The reclassification is done on the following basis: multiply the number of tons of coal found in a particular region by the midpoint of the particular sulfur content class. This yields the implied amount of sulfur in that coal. Applying this implied amount of sulfur to the coal reserve found on a comparable Btu basis, yields the amount of sulfur on an "effective" basis. Thus, as an example, in the 0.8 to 1.0 percent sulfur content category for northern Appalachian bituminous coal, the midpoint of the sulfur class is 0.9 percent sulfur by weight as found in Table 5. The known recoverable reserves found in Table 2 under that sulfur classification are 360 million short tons. Multiplying the two yields 3.24 million tons of sulfur. Dividing this figure by 432 million short tons of coal (which is the northern Appalachian known recoverable reserve found in Table 4 in the 0.8 to 1.0 percent sulfur content classification) implies that the effective sulfur content for this northern Appalachian coal averages not 0.9 but 0.75 percent on a consumption basis. The implied average sulfur content noted in the parentheses in the body of Table 5 indicates the classification in which the reserve estimate actually belongs. Combining Table 5 sulfur classifications with the Table 4 constant Btu estimates produces Table 3. Alternatively, Table 3 combines the sulfur classification placement or reassignment found in Table 5 with a consistent Btu estimate of reserves found in Table 4.

One caveat must be noted immediately. For computational purposes it is necessary to deal with each sulfur classification as if it were a point estimate rather than a range estimate. Clearly, however, the sulfur content of coal in each classification is distributed around the midpoint of the range. Thus, in the shifting of coal reserves from class to class, it is not necessarily true that all of the coal would or should have been shifted. On the average, however, it is true. The available data simply do not permit a more adequate handling of this problem.

2. Sulfur Removal by Washing

Some reduction in the sulfur content of coal may be achieved by crushing and washing. This removes some, but not all, of the pyritic sulfur at the cost of losing some of the coal. Table 6 indicates the available reserves of low sulfur coal by sulfur content based on two assumptions. First, washing is continued until a maximum of 10 percent of the material (coal, ash, etc.) is lost and grinding yields a particle top size of 3/8 inch.[18] Second, it is assumed that the coals tested by Duerbrouck are representative of the coal reserves found in each region. In the calculation of Table 6, the estimates were made by adding to the resources and recoverable reserves already in the $\leq$ 0.7 percent sulfur category, those reserves from higher sulfur percent categories that could be reduced to a $\leq$ 0.7 percent sulfur level by washing. A similar procedure was used for the 0.8-1.0 percent sulfur category. However, if some or all of the resources and recoverable reserves had already been moved from the 0.8-1.0 percent sulfur category to the lower one, the base to which coal from still higher sulfur categories might be moved would necessarily be smaller.

The figures in Table 6 should be compared with those in Table 3. The $\bar{x}$ estimate refers to the average sulfur reduction due to washing, the -1σ column is a pessimistic evaluation of washing, and the $+1\sigma$ would account for an optimistic evaluation of the sulfur reduction in coals due to washing. Thus, in comparing Table 6 with Table 3 at the two lowest sulfur levels, an optimistic evaluation would compare Table 3 reserves with the $+1\sigma$ columns in Table 6 for both the $\leq$ 0.7 percent sulfur in the fuel and the 0.8 to 1.0 percent sulfur in the fuel.

The sulfur content in the fuel after washing depends on the initial sulfur content, the relative amount of pyritic to organic sulfur, and on the dispersion of the pyritic sulfur within the fuel. The ranges may be very broad and Table 6 should be viewed primarily as indicative. It does give some idea, however, of what can be achieved with current technology. While the basis for the tonnage figures in Table 6 are to be found in Table 3, the approximate sulfur reduction as a percent is found in Table 7. As Table 6 may also be considered a reevaluation of the effective sulfur content of coal reserves subject to sulfur

Table 6

United States Coal: Resources and Recoverable Reserves of Low Sulfur Coal After Sulfur Reduction by Washing (Jan. 1, 1965) - Selected Regions

(10^6 Short Tons)

	Sulfur Content (Percent)					
	$\leq$ 0.7			0.8-1.0		
	-1σ	$\bar{x}$	$+1\sigma$	-1σ	$\bar{x}$	$+1\sigma$
Appalachian, North	3360	3360	29004	25644	25644	27660
	438	438	3774	3336	3336	3594
South	44730	93960	93960	49230	21762	21762
	4920	10332	10332	5412	2394	2394
Total	48090	97320	122964	74874	47406	49422
	5358	10770	14106	8748	5730	5988
Interior, Total	472	2101	2101	1629	9931	9931
	74	343	343	269	2047	2047
Rockies, Total	94910	94910	285469	190559	490364	622184
	9557	9557	29761	20204	53177	67457

Source: Tables 7 and 3. Anthracite is excluded.

reduction by washing, it can be compared with Table 2 which may be considered reserves according to the conventional wisdom exemplified by DeCarlo, Mitre, and the National Petroleum Council.

Because of the loss of material in the washing process, some of the heat content originally found in the coal is lost. However, the relationship between the amount of material remaining and the Btu content remaining after washing is not simple. The material lost includes coal, ash and sulfur. The Btu content accrues to the first. Given the data on ash reduction found in Duerbrouck, an estimate of the heat content lost by washing coal to a 90 percent material yield could be made.(19) It has not been done here. It can be said, however, that washing to a 90 percent material yield implies a heat content loss of less than 10 percent. However, the variations among coals with respect to the heat loss are wide. In sum, a comparison between the results in Table 6 with those in Table 3 overstates the sulfur reduction due to washing by a small amount.

The amount of coal in each class in Table 6 depends on the reserves, the approximate percentage sulfur reduction due to washing, and the reliability of the estimate. Thus, Midwest or Interior coals do not gain as much by washing as do those from the northern Appalachian district, because the approximate sulfur reduction due to washing is usually lower. In addition, and more importantly, as seen in Table 3 the total amount of low sulfur coal in the Interior region is less than that in the Appalachian region.

In terms of reliability, it should be noted that the West Coast region is omitted from the calculations. The total tonnage of both low and high sulfur coal omitted, if Alaska is excluded, is relatively insignificant. In the Rocky Mountain region the figures in Table 6 and 7 refer to a conglomerate of bituminous, subbituminous and lignite coals. The reliability of those figures must be considered as less than that for the Appalachian or Interior regions.

Some coal reaches the consumer after having been washed to some degree. As noted above, DeCarlo mentions that his analyses were based on cleaned coals. To the extent that washing is the current practice, Table 6 overstates the advantages of washing and overstates the recoverable reserves that can be reduced to the $\leq$ 0.7 and the 0.8-1.0

Table 7

Coal: Approximate Sulfur Reduction By Washing

	Material Content After Washing (%) 90			80		
	Approximate Sulfur Reduction (%)					
	-1σ	$\bar{x}$	$+1\sigma$	-1σ	$\bar{x}$	$+1\sigma$
Appalachian, North	16	31	42	23	41	60
South	0	10	21	0	10	20
Midwest	11	24	34	20	32	45
West	3.1	5.2	7.1	4.8	5.6	8.1

Source: **A. W. Duerbrouck**, Sulfur Reduction Potential of the Coals of the United States, Bureau of Mines, RI7633, (1972). Data are derived from figures on pages 233, 265, 269 and 283. Assumes grinding to 3/8 inch top size.

Table 8

Low Sulfur Coal: Comparative Estimates of Resources and Recoverable Reserves in the ≤ 0.7 Percent Category (Jan. 1, 1965) (10^6 Short Tons)

	Conventional(1)	Standardized(2)	Standardized with Washing Pessimistic(3)	Standardized with Washing Average(4)	Standardized with Washing Optimistic(5)
Bituminous Coal					
Appalachian, North	45	54	3360	3360	29004
	5	6	438	438	3774
South	37275	44730	44703	93960	93960
	4100	4920	4920	10332	10332
Total	37320	44784	48090	97320	122964
	4105	4926	5385	10770	14106
Interior, East	195	207			
	50	53			
West	250	265			
	20	21			
Total	445	472	472	2101	2101
	70	74	74	343	343
Rockies, North	6275	6526			
	690	718			
South	38940	42055			
	3895	4207			
Total	45215	48581	94910(6)	94910(6)	285469(6)
	4585	4925	9557	9557	29761
West Coast	900	855			
	80	76			
Bituminous Coal-Total	83880	94692			
	8840	10001			

Subbituminous Coal					
Rockies, North	129665	-			
	14265	-			
South	52005	46329			
	5205	4632			
Total	181670	46329			
	19470	4632			
West Coast	3780	-			
	340	-			
Subbituminous Coal-Total	185450	46329			
	19810	4632			
Lignite	344620	-			
	37905	-			
Anthracite	12550	14056			
	1630	1826			
Total-All Ranks	626500	155077	155995(7)	206881(7)	423084(7)
	68185	16459	16646	22300	45840

(1) Table 2, column 1.

(2) Table 3, column 1.

(3) Table 6, column 1.

(4) Table 6, column 2

(5) Table 6, column 3

(6) Includes bituminous, subbituminous and lignite. Comparable figures for these three ranks in this table are 571505 in column 1
61960
and 94910 in column 2.
9557

(7) Includes unwashed anthracite (Table 5 column 1) as a constant in all three estimates at 12550.
1630

percent sulfur categories. In 1969, the Bureau of Mines analyzed 298 samples of tipple and delivered coal. Of these, 190, or 63.8 percent, were washed or partially washed. In 1972 only 166 samples were taken. Of these only 88, or 53 percent, were at least partially washed.[20] It is not known how representative the number of samples are with respect to the total tonnage of coal delivered. Regionally, in terms of the number of samples analyzed, washed coal in the Appalachian area declined from 67 percent in 1969 to 49 percent in 1972. It increased in the Interior region from 69.5 percent to 81.1 percent for those two years. Only 22.2 percent of the samples of Rocky Mountain coal was reported as washed in 1969, this rose to 26.1 percent in 1972. Excluding Alaska, no samples were reported for the West Coast region.

Table 8 presents a comparison of coal reserves and resources in the low sulfur category. Column 1 is the conventional form found in DeCarlo/Mitre/National Petroleum Council and others. It represents the simple addition of tonnages without regard to Btu content. Column 2 is the revision of the first column based on a standardized Btu content and the resultant reclassification of the reserves in terms of sulfur category. Columns 3-5 indicate the size of the standarized reserves (Column 2) given specific assumptions concerning the reduction of the sulfur content in coal due to washing. By way of comparison, the Mitre study[21] estimates that known bituminous coal reserves remaining in 1968, assuming that all are to be crushed to a 3/8 inch top size and washed to the 90 percent yield point, are (in millions of equivalent tons) 9930 in northern Appalachia, 44840 in southern Appalachia, and 790 in the eastern Interior region.

SECTION III

PRODUCTION ESTIMATES-LOW SULFUR COAL

Coal production in the United States in 1970 amounted to 611.5 million tons. The regional totals are listed in Table 9. An estimate of low sulfur commercial steam coal production is presented in Table 10. In comparing these two tables it should be noted that the only coal in the United States for which shipments averaged one percent sulfur or less on a raw coal unadjusted basis came from district 7 (Southern numbered 1) and districts 16-22 which include northern and southern Colorado, New Mexico, Wyoming, Utah, and North and South Dakota.[22] The comparison implies that most of the coal mined in the southern Appalachian and both Rocky Mountain regions are, in terms of the raw coal unadjusted sulfur content, low sulfur. In 1970, low sulfur commercial steam coal, as a percentage of total coal production, was reported to be about 74 percent in southern Appalachia, 76 percent in the northern Rockies and 80 percent in the southern Rockies. Lignite production in the northern Rockies was reported as totally low sulfur, on a raw coal or conventional basis.[23] It should be emphasized again that the comparison being made is between low sulfur commercial steam coal production and total coal produced in 1970. The distribution of bituminous and subbituminous coal and lignite among consumers is presented in Table 11. It can be seen that coal used directly for steam raising amounted to 65.8 percent of the total if only electric utilities are included. The addition of all other classes, except exports and coke and gas plants, raises this total to 74.7 percent. Some, but not much, of the exports are steam coals. In 1970, only 10.3 percent of our non-Canadian exports of bituminous coal were steam coals.[24] Metallurgical grade coal is almost always low sulfur. This amounted to 103 million tons going to coke and gas plants and a total of 53.8 million tons exported in 1970.[25]

Not all coal production is commercial. Table 12 shows some selected relationships between open market and other (captive) market production.

The Hoffman study[26] indicates that in 1969 the coal industry contemplated a growth rate of 7 percent per year through 1973. Over

Table 9

U.S. Coal Production - 1970
(10^6 Tons)

Region		Rank: Bituminous and Subbituminous	Rank: Other
Appalachia,	North	82.1	9.3 (Anthracite)
	South	280.4	
	Total	362.5	
Interior,	East	195.5	
	West	9.6	
	Total	205.2	
Rocky Mountain,	North	10.4	5.9 (Lignite)
	South	18.2	
	Total	28.6	
West Coast (ex. Alaska)		.04	

Total -	Bituminous and Subbituminous	596.3
	Anthracite	9.3
	Lignite	5.9
	All Ranks	611.5

Source: Department of the Interior, Minerals Yearbook, Vol. 1, (1970), pp. 334, 336, 392. Parts may not equal totals due to rounding.

Table 10

Regional Production of Low Sulfur Commercial Steam Coal (1970)
(10^6 Tons)

	Sulfur Content (Percent) < 0.7			.07-1.0		
	Rank					
	Bituminous	Subbituminous	Lignite	Bituminous	Subbituminous	Lignite
Appalachian,[1] North	0	-	-	.13	-	-
South	140.0	-	-	66.1	-	-
Total	140.0	-	-	66.23	-	-
Interior, East[1]	.16	-	-	.13	-	-
West[2]	.32	-	-	.19	-	-
Total	.48	-	-	.32	-	-
Rockies, North[2]	.11	12	2.9	-	-	3.2
South[2][3]	2.2	10.5	-	1.8	-	-
Total	2.31	22.5	2.9	1.8	-	3.2
Total	142.8	22.5	2.9	68.4	-	3.2

Source: L. Hoffman, Survey of Coal Availabilities by Sulfur Content, Report to the Environmental Protection Agency, Mitre Corporation, MTR-6086,(May 1972). Anthracite is excluded

(1) Derived from Table XLVIII page 109, assuming a 7 percent growth rate.

(2) Based on Figures 7-9 pages 32-34, numbers courtesy of L. Hoffman.

(3) Includes West Coast but excludes Alaska.

Table 11

Distribution of Bituminous Coal and Lignite, 1970, by Consumer Use

	10^6 Tons	Percent
Electric Utilities	339.4	56.8
Coke and Gas Plants	103.0	17.2
Retail Dealers	14.8	2.5
All Others	86.5	14.5
Railroad Fuel	.8	.1
Used at Mines, etc.	1.5	.2
Canadian Great Lakes, etc.	.3	-
Overseas Exports	51.8	8.7
Sub total	597.9	100
Net Change in Mine Inventory	+.07	
U.S. Great Lakes Dock Storage	-.02	
Total	598.0	

Source: Department of the Interior, Minerals Yearbook, 1970, p. 376. Sum may not add to total due to rounding.

Table 12

Nonmarket Production of Bituminous Coal, 1970
(000 Tons)

Production from Consumer Owned Captive Mines

Industry	Amount	Percent
Steel	65,372	10.8
Electric Utility	15,165	2.5
Others	8,149	1.4
Total	88,686	14.7
Total Production	602,932 (1)	100.0

Production of Bituminous Coal Not Sold in the
Open Market, 1970, Selected States

State	Total Production (2)	Production Not Sold in Open Market	Percent
Alabama	20,560	7,896	38.4
Illinois	65,119	2,136	3.3
Kentucky	125,305	8,364	6.7
Pennsylvania	80,491	29,529	36.7
West Virginia	144,072	18,843	13.1

Source: National Coal Association, Bituminous Coal Data, 1971 edition, p. 15.

(1) NCA, *op. cit.*, p. 13.

(2) NCA, *op. cit.*, p. 18.

90 percent of the additional output was to be absorbed by exports and electric generation. While that study applied the growth rate equally across all sulfur classes, such a procedure does not appear entirely reasonable. In order to test the adequacy of reserves in the light of air pollution control regulations and premium prices for low sulfur coal, it is more reasonable to apply the entire growth potential to low sulfur coal.

A 7 percent growth rate,[27] given production of 611.5 million tons in 1970, implies coal production of: 857.7 million tons in 1975, 1203.0 million tons in 1980 and 1687.3 million tons in 1985. In turn, this implies cumulative production from 1970 to the end of 1975 of 4,374.2 million tons; to the end of 1980 of 9,652.0 million tons; and to the end of 1985 of 17,054.6 million tons.[28] This includes coal of all ranks and is on a simple weight basis. The comparison of potential production is therefore made first with Table 5 column 1 estimates which indicate the usual tonnage but the adjusted sulfur basis.

Inspection indicates that by 1985 known recoverable reserves would be insufficient by a total of 1.4 billion tons. Furthermore, cumulative production between 1970 and 1985 would amount to over 11 percent of the total known reserves in the $\leq$ 0.7 percent sulfur class on a sulfur adjusted basis. If coal policy is based on the conventional estimates found in Table 2 column 1, no such problem exists. Cumulative production from 1970 to 1985 would be less than known recoverable reserves by 51.1 billion tons and represents only 2.7 percent of known reserves in the $\leq$ 0.7 percent sulfur category.

Extending the comparison to the standardized Btu and washed coal bases found in Table 8 columns 2-5 does not significantly improve the prognosis. Known recoverable reserves of low sulfur coal are inadequate except for the average and optimistic estimates of sulfur reduction by washing. Even in these two categories, estimated cumulative low sulfur coal production between 1970 and 1985 is equal to 8.2 and 4.0 percent respectively of the 1965 estimated known low sulfur coal reserves indicated in columns 4 and 5. The issue of whether the comparison should be based on known reserves or on known recoverable reserves is discussed below.

The 7 percent growth rate in production assumed in this paper should be compared with other calculations of this rate. The National Petroleum Council considers 5 percent per year to be the maximum feasible for the conventional domestic market. However, this is increased to 6.7 percent per year if production for exports and synthetic fuels are included.[29] The increase in production rates, due simply to an additional market, makes it obvious that their estimate is a demand rather than a maximum supply estimate. However, their result is close to the one used here. Risser[30] notes that short term increases in mining capacity are limited due to the lack of current mine openings. The reasons cited include: competitive oil imports, nuclear planning by electric utilities, mine safety regulations, environmental controls and manpower and railroad car shortages. To this list may be added a shortage of funds in the east; most investment is going toward the opening of western stripmines. The growth in coal production in Montana increased 33 percent between 1972 and 1973. The third largest mine in the U.S. expects to increase its output by 42 percent between 1972 and 1976. Part of this growth potential is explained by recalling that it takes up to six years to open an underground mine but less than three years to open a stripmine.[31]

SECTION IV

FACTORS AFFECTING RESOURCE, RESERVE AND PRODUCTION ESTIMATES

Earlier in this paper it was shown that, for computational purposes, it was necessary to treat the coal tonnage value in each sulfur range category as if the value accrued to the midpoint of the range. Given the data, this is unavoidable. The point is, however, important enough to be reiterated. Not only are the tonnages of coal assigned to a sulfur range distributed within that range but, given the original estimating procedures, at least some of that coal does not belong in that range. Thus, shifting of tonnages, in terms of either production or reserves, to a different sulfur category need not really mean that all of the coal should be shifted. However, until data are very carefully collected and arrayed on a mine by mine or seam by seam basis, there is little more than can be done with the problem than to treat the existing data with some awareness and diffidence.

A. Stripmining and Mine Safety Legislation

The second warning required concerns stripmining and mine safety as these are related to both reserve and production estimates. While both could be discussed in the following sections, neither of them are related directly to low sulfur coal alone and are best disposed of here.

For whatever purpose imposed, the result of safety and stripping legislation is to raise the cost of production. This will not only forestall production in certain areas and/or specific mines, it will decrease that quantity of coal defined as known recoverable reserves. Even this may be only temporary. If the price of coal rises sufficiently to cover reclamation and safety costs, production will recommense and the reserve will again be recoverable, according to definition. Coal is not fugacious. Halting production or shifting reserve categories does not imply that the resource is lost, it is merely postponed. The same arguments hold with respect to added costs of production due to increased unionization in western coal fields or shifts of workers between unions.

In this paper, the effects of these output limiting forms of legislation have been omitted. Regionally, it is difficult to say where the impact would be greatest. Western coal is not yet really

produced to capacity but it has been shown that the recoverable reserves of low sulfur coal in that region are not nearly at the level indicated by conventional estimates. An analysis of the effects field by field and seam by seam would be necessary to ascertain the relative regional effects on the production or reserves of low sulfur coal due to, say, prohibiting contour stripmining. The National Petroleum Council, however, has estimated that the elimination of contour mining would result in the loss of 4.4 billion tons of recoverable reserves.(32) Risser has noted that mine safety regulations have reduced output per man per day in underground mines from 15.61 tons in 1969 to 12.03 tons in 1971.(33) This trend could be reversed by the expanded use of European style longwall mining techniques.

One thing is certain, simple quotation of the number of mines closed because of safety or other regulations is virtually meaningless. In 1970, bituminous coal was produced in 5601 mines. Of these, 4006 or 71.5 percent produced only 9.9 percent of the total production. The top size of these mines was only 50,000 net tons.(34) Most closures will be among these small mines. It would be unfortunate if energy or coal legislation were pinned to their necessary survival.

B. The Effect of Sales Prices

The foregoing analysis must also be tempered by an understanding of the estimation of reserves and their classification. The commonplace consideration of production or output as dependent directly upon price is a simple statement of the supply curve. It is equally true, however, that reserves are also a function of price. For this reason, estimates of resources and reserves made by the U. S. Geological Survey, DeCarlo, Mitre and the National Petroleum Council, are not ultimate figures, but are themselves dependent upon the sale price and costs of production ruling at the time the estimates were made. It is therefore probable that as coal prices continue to rise, resource and reserve estimates of coal will also rise somewhat. This does not mean that additional recoverable reserves of low sulfur coal will be found. It is not possible to search only for low sulfur coal. However, it is probable that as new coal reserves are found or developed that the low sulfur coal segment will be produced preferentially.

Increases in coal resources and recoverable reserves occur when previously undiscovered resources are discovered. This requires an active exploration program. Increases may also occur because resources which are already known to be available move from the class of known reserves to the higher class of known recoverable reserves or from submarginal reserves to recoverable reserves. In either case, price is the driving mechanism. The willingness to explore in the hope of finding something must be matched against the expense of the exploration. In the event that something is found it is rendered profitable and therefore exploited because of the anticipated sales price. The movement of known reserves into the recoverable category from the submarginal or merely known category is due to price increases making it profitable to increase the recovery factor in existing mines, to develop thinner beds and seams and to engage in secondary recovery. All of these are more costly than existing coal mining operations.

As an example of possible resource and recoverable reserve additions due to exploration, it may be noted that it is probable that reserve estimates of coal in the Rocky Mountain areas are understated. Less is known about that region than is known, for example, about coal resources in the Appalachian region. For many years, there was little production in the Rocky Mountain area simply because of the distance to markets and the resulting transportation costs; exploration in this area was less valuable than exploration in other areas of the country. Therefore, FOB mine prices were relatively low, production was relatively low and the search for reserves was probably not pushed extensively. The National Petroleum Council has argued that further mapping and exploration, especially in the western states, should result in substantial increases in the U. S. Geological Survey's estimates of coal reserves that can be mined with existing technology.[35] They show that the ratio of "unmapped and unexplored" coal resources to total resources is 73 percent in Wyoming, 41 percent in Montana and 34 percent in North Dakota. In the Midwest the ratio is 42 percent in Illinois and 39 percent in Indiana. In the East, the ratio is very much lower; 13 percent in Pennsylvania and zero percent in West Virginia.[36]

Resource increases due to changes in the classification of resources are exemplified by the definitions of resources used by the U. S.

Geological Survey.[37] The U. S. Geological Survey's estimates are broken down into identified and undiscovered resources. The identified are those recoverable either in thick beds, in thin beds, or those that are submarginal, meaning that at current prices for the product and costs of production it is not economically feasible to remove the coal with current technology. For both anthracite and bituminous coal thick beds are those greater than 42 inches. For lignite and subbituminous coal, a thick bed is defined as 10 feet or more. The differences in thickness represent, in part, the differences in heat value and, therefore, in economic evaluation. In all cases, the distance from the surface must be less than 1000 feet. The Survey indicates that the recovery factor for these coals is estimated to be 50 percent. Thin beds for anthracite and bituminous coals are those from 28 to 42 inches thick while for subbituminous and lignite they are from 5 to 10 feet thick. Again, the recovery factor is only 50 percent and the distance to the surface is less than 1000 feet. Submarginal coal includes that coal left in the ground during the first mining operation, coal in depths from 1000 to 6000 feet below the surface, and coal in very thin beds. Undiscovered coal includes those resources not mapped or not sampled but which are within known coal fields. The Survey goes on to note that all fields are known in some degree.

It should be clear that all of the factors which contribute to the defining of a coal seam by resource class depend upon the cost of production and the sale price. As the price of coal rises or as the price of competing fuels rise, making coal more competitive, it pays to look at thinner beds and to develop them. It also pays to look for coal with a greater overburden and it pays to engage in secondary recovery or more careful primary recovery, thereby increasing the recovery factor to more than 50 percent. In short, the implied added costs are compensated for by the higher price.

As low sulfur coal becomes a premium fuel, it is to be expected that economically recoverable reserves in this category will rise simply by redefinition. As prices rise, even thin beds and coal deposits heretofore considered inaccessible for shipment become economically much more interesting. The DeCarlo study, upon which much of the Mitre study was based, provided reserve estimates for January 1965. If prices were

specifically considered, they would have been 1964 prices. The average value of U. S. coal per net ton FOB mines sold in the open market rose from \$4.34 per ton in 1967 to \$6.66 per ton in 1971.[38] This is an increase of over 53 percent. The average value of bituminous coal sold in the open market in 1964 was \$4.11, in 1965 it was \$4.13.[39] The increase from 1964 to 1971 was 62 percent. It is more than likely that increases of this magnitude were sufficient to generate more economically recoverable reserves of coal by shifting from classes or categories of lower recoverability to those representing higher recoverability. As the low sulfur categories were already beginning to move to a premium, such reserve shifts were even more likely in these categories. It was for this reason that 1970 figures and forecasts based on 1970 production were made against those of DeCarlo/Mitre for 1965 without an alteration in the latter. This is also the reason for making comparisons using both known reserves (DeCarlo) and known recoverable reserves (Mitre) as the base.

In the Mitre study, the first order estimates of known recoverable reserves (reproduced in Table 2) were made by using the same recovery factor for all sulfur categories in each region. In the face of premium prices for low sulfur coal and the growing demand for the product, even if that were an acceptable procedure at the time of the report, it is very unlikely now that the same mining recovery factor exists for low sulfur coal as for high sulfur coal in any of the geographic regions studied. The use of the same recovery factor for all sulfur categories will be still more unreasonable in the future. A much more probable scenario is one in which reserves of low sulfur coal are increased, now and in the future, simply because the mine recovery factor attributable to these reserves is higher than the recovery factor for the higher sulfur categories.

Another way of looking at the price that low sulfur coal can command is to consider a near substitute: No. 6 residual fuel oil. At the end of the summer 1973, New York cargo lots of 1.0 percent maximum sulfur No. 6 fuel oil were priced at \$4.43 - \$4.61 per barrel. Assuming 6.287 million Btu per barrel for residual oil and 22.6 million Btu per ton for coal this equates to a coal price of \$15.90 - \$16.55 in New York harbor. A 0.5 percent maximum sulfur residual oil on the same date sold

for $4.92 - $5.21 per barrel. The coal price equivalent was $17.66 - $18.70 per ton.[40] From the same publication, Midwest prices can be estimated. The price of Oklahoma residual oil for northern shipment with a 0.75 percent maximum sulfur guarantee was $2.75 - $3.00 per barrel equating to $9.87 - $10.77 per ton for coal. In Chicago, in tank car or tank wagon lots, 1.0 percent maximum sulfur guarantee No. 6 residual fuel oil sold for $5.46 - $5.88 per barrel. This equates with a price of $19.60 - $21.11 per ton for coal. Since the oil was used primarily by public utilities for electric power generation, it would seem reasonable that utilities would be willing to pay slightly less for coal with comparable sulfur characteristics. The slightly reduced price is necessary to offset additional costs incurred in coal handling and storage at the utility. Nevertheless, the implied price of this low sulfur coal should be sufficient to shift some coal in the low sulfur category from submarginal to paramarginal and from paramarginal to economically recoverable. This does not mean that reserve estimates of low sulfur coal are adequate in the light of air pollution control regulations, but it may mean that the recoverable reserve balance is not quite as bad as the figures in the previous section of this paper indicate.

SECTION V

POLICY OPTIONS AND ALTERNATIVES

Given the shortages of low sulfur coal implied in the second part of this paper, coal policy alternatives are limited to conserving low sulfur coal, utilizing high sulfur coal and identifying new reserves. The first is short term, the latter are essentially long term solutions. The following discussion outlines some of the options and their parameters. It is assumed that total consumption will not be altered. Therefore, favorable consideration of a long range option implies a significant effort toward shortening the time in which it will become operational.

A. Short Term: End Use Controls

In the very short run of one or two years, properly characterized as a time of specific fuel shortages rather than as an energy crisis, conservation implies end use controls for low sulfur coal. These would apply primarily to the export market and to the iron and steel industry. Transfers would be made from mines supplying these users to the public utility sector. Shipments of low sulfur bituminous coal to coke and gas plants in 1970 averaged about one percent sulfur. Exports, including, Canada, average 0.9 percent sulfur by weight.[41] U. S. exports of solid fuels in 1970 amounted to 789,000 tons of anthracite, 70.9 million tons of bituminous coal, 2.5 million tons of coke, and 69,000 tons of briquets.[42] In 1970, exports of bituminous coal to Canada were 18.7 million tons while anthracite coal shipments to Canada amounted to 443 thousand tons.[43] Therefore, other exports totaled 52.2 million tons of bituminous coal and 346 thousand tons of anthracite in 1970. Of the Canadian shipments, 37 percent were metallurgical grade coal, essentially low sulfur coal, while for the rest of the world, shipments of metallurgical coal were 89.7 percent of the total.[44] In sum, of the total exports of 70.9 million tons of bituminous coal, 75.8 percent of 53.8 million tons of bituminous coal was low sulfur metallurgical grade.

Exports of low sulfur coal need not be expected to grow at the 7 percent rate assumed earlier in this paper; however, it is probable that future shipments will exceed 1970 levels. The National Petroleum Council expects U. S. exports of coking coal to grow from 56 million tons per year in 1970 to between 120 and 150 million tons per year in 1985.[45]

Exports of utility fuel are expected to rise from 15 million tons in 1970 to 18 million tons in 1985.(46)

Exports of a scarce resource are a matter of both commercial and national policy. On the national level, there is no apparent reason why coal exports cannot be treated in the same manner as current oil exports are treated by Middle Eastern countries or as Canadian exports of oil and gas to the United States are treated. Furthermore, to the extent that reserves of low sulfur U. S. coals are committed long term for export purposes at preexisting prices, a two-tier price system is likely to arise in the United States. On the one hand, the demand for low sulfur coals for domestic consumption and the increase in price of domestic and imported alternative fuels will drive domestic low sulfur coal prices higher. On the other, long term price committments with respect to export coals will leave those coal prices at a relatively lower level. At a minimum, to avoid market tensions, renegotiation of long term coal contracts should take place periodically. This is precisely the Middle Eastern or Canadian solution. The restriction of exports has an adverse balance of payments effect on the United States. To the extent, however, that restriction of coal exports leads to relatively lower energy and steel costs in the U. S. compared to Europe or Japan, the adverse balance of payments effect may be mitigated.

The use of coal by the iron and steel industry is based primarily on the production of coke. Specific coals are necessary because the coke must be porous and have a high degree of structural strength. The low sulfur requirement is due to the transfer of much of the sulfur in the coke to the metal during processing. At present prices, there can be little substitution for coke. Petroleum coke is not a substitute while, in terms of current technology, methods which do not use coke involve direct reduction followed by melting to float off impurities. Relatively high sulfur coking coals can be blended with low sulfur coking coal if manganese is used to scavenge the additional sulfur. This process requires additional limestone to flux the sulphate. Therefore, total capacity is reduced, more costly processing components are required and output cost per unit is increased. However, as the price of low sulfur coking coal also moves to a new higher premium, at some point, a balance is struck between the excess premium for the low sulfur

coal and the use of higher sulfur coking coals. This may result in a saving of the low sulfur reserves for other purposes. It is not likely, however, that these forms of low sulfur coal savings will be available in the near future. The costs of the changes are high and the technology is relatively new. The modern American steel industry is not known for its adaptability or its rate of technological change.

Table 12 presents some data on the nonmarket production of bituminous coal from captive mines. These mines are typically owned by firms in the steel industry. Some are owned by electric utilities, still others by oil companies. To the extent that air pollution control standards and the use of low sulfur coal are deemed to outweigh private commercial considerations, such coal could be made available for sale on an end use control basis to the general market; in particular to public utilities. Such transfer, however, does not increase reserves. It merely allows a change in the time horizon of their use and increases their market availability.

B. Long Term: Use of High Sulfur Coal

1. Reduction of Air Quality Standards.

Long term energy policy with respect to coal must center on the use of high sulfur coal. The simplest solution for both our present problem and most future energy problems would be to remove or reduce EPA emission control regulations which lead to the restricted use of high sulfur coal. This is being accomplished, in part, by a delay in the implementation of secondary emission standards and can be furthered by their total removal. On the state level, for example, there are efforts in the Illinois State Legislature to prevent state Air Pollution Control Board regulations from restricting the use of Illinois coal, most of which is in the high sulfur category. The Environmental Protection Agency in Ohio is proposing to change some aspects of its sulfur dioxide emission control program. These changes include extending the deadline for control and drawing up new geographical boundries for localities such that more areas can burn Ohio's indigenous high sulfur coal. On the other hand, construction of coal fired power plants in the Four Corners area are being held up, in part on air pollution grounds. Others in the area must stipulate that they will meet all present and future pollution control requirements.

The current fuel emergency situation is being cited as a reason for allowing the burning of high sulfur coal for the duration of the emergency or indefinitely until the situation changes. Unless and until the electric utilities in all of the regional councils are required to share their capacity via the national transmission network, the justification for this is unclear. The current fuel problem is in the petroleum area and affects neither coal mine capacity nor output nor markets. Most boilers in electric utility power plants burn only one fuel as their primary fuel. Unless they are equipped with multiple fuel capacity boilers, they cannot switch without significant equipment changes. Without sharing power loads, an east coast oil induced power shortage has no effect on power demand in the midwest where coal is used. If electric power is shared, however, coal based electric power can be bumped towards the east coast, sharing the shortage, alleviating the petroleum problem and, perhaps, justifying the use of high sulfur coal in the Midwest during the emergency.

Neither the sulfur content of coal nor the current fuel oil shortage can be blamed for the shortage in electric utility generating capacity. Brownouts have occurred over the past two years. Given the time lag in plant construction, the causes of this shortage must be looked for, at least in part, in the period predating the Clean Air Act.

2. Coal Gasification and Liquefication.

Preservation of air quality standards, while utilizing reserves of high sulfur coal, requires the desulfurization of the coal before, during or after combustion. Coal gasification and liquefication both offer a means of desulfurizing high sulfur coal before combustion. However, both are energy conversion processes of less than 100 percent efficiency. In order for this type of conversion process to be useful it must be an energy upgrading process. That is, one in which an inferior form of energy is used as an input to produce a superior or more useable form of energy. In this sense both synthetic natural gas and liquefied coal are superior in use to coal itself. Both are low sulfur, easily and cheaply transported and stored, and both can be used in more applications than coal.

The thermal efficiencies of coal gasification processes currently available, where the product is a high Btu pipeline quality gas with an energy content ranging from 900 to 972 Btu/SCF, range from a low of 48.1

percent for the Hygas process to 68.8 percent for the Lurgi process. The thermal efficiencies for low Btu fuel gas, ranging from 250 to 500 Btu/SCF, range from 66 percent to 80 percent. This type of gas would be used directly by steam electric plants.[47] Where the product made from high sulfur coal is a low sulfur liquid fuel, the thermal efficiency of the process is about 76 percent. For solvent refined coals, such as those produced by the Pittsburgh and Midway Coal process (which yields a power plant fuel with about 15,900 Btu per pound), the thermal efficiency is about 75 percent.[48]

Since the efficiency of these processes is not 100 percent, air pollution control requirements predicate a sacrifice of some high sulfur coal if any high sulfur coal is to be used at all. While there is obviously an energy cost to air pollution control due to gasification or liquefication, it should also be noted that this is the standard practice in the upgrading of fuels. For example, the production of gasoline requires the use of energy which would not have been consumed if propulsion mechanisms ran on crude oil.

One of the major problems in the implementation of coal gasification technology is the water requirement. A number of sites for these plants have been identified on the basis of adequate water supply. Some, however, may be too close to densely populated areas or are otherwise unacceptable. The water problem is not trivial. In coal gasification, water is used as a process input, the source of the hydrogen which, when added to the carbon in coal, produces synthetic methane. It is not simply used as a collant and returned to its source. However, despite the water problems in the Rocky Mountains area, the National Petroleum Council's analysis of synthetic fuels has a totally western orientation. No mention is made of water requirements. Coal gasification is expected to be based on bituminous coal from New Mexico, subbituminous coal from Wyoming and Montana and lignite from Montana and North Dakota.[49] The study anticipates that the synthetic natural gas can be profitably sold at between $.90 - $1.10/MMCF at the Rocky Mountains region plant and, with the addition of pipelining costs, at $1.10 - $1.40/MMCF in the midwest.[50] As these are 1970 prices, some allowance must be made for inflation. Comparing these prices with those of imported liquefied natural gas and unregulated intrastate sales of domestic natural gas suggest the reason that at least one coal gasification plant is being

constructed. It should be noted, however, that given water problems, distance from major markets (which requires extensive pipelining), and available economically recoverable reserves, coal gasification plants in the states of Illinois, Indiana and Ohio would appear to be economically superior to those in the Rockies.

Coal liquefication, used in Germany during World War II reportedly does not have a proven economically feasible technology.(51) While the U. S. Navy has already run a destroyer on a coal-derived oil,(52) this does not prove economic feasibility. Given 1970 costs, the National Petroleum Council has estimated that the syncrude price would be about $7.50/barrel. This compares favorably with current Middle Eastern prices plus transport. Where the process yields not a synthetic crude oil but a low sulfur fuel oil (0.3 - 0.5 percent sulfur), the estimated price is $4.50 - $5.50/barrel.(53) Again, these prices compare favorably with imported low sulfur residual oil prices.

3. Stack Gas Scrubbing.

Stack gas desulfurization removes the sulfur content of the coal after combustion. An extensive literature concerning the pros and cons of the use of such processes is available and will not be dealt with here.(54) Some points may be made in passing, however, as stack gas desulfurization offers one route for maintaining air quality standards while allowing the use of high sulfur coal. Additionally, the fuel sacrificed in this process is less than that for either gasification or liquefication. The energy penalty for stack gas scrubbers, including particulate removal, is reported to be approximately 8 percent.(55)

The average sulfur content of coal used for electric power generation in the United States is about 2.5 percent. At least 90 percent of the sulfur in the fuel appears in stack gases as sulfur oxides. As shown in the first part of this paper, the minimum value of sulfur in coal that can be used as fuel without any controls decreases as the heating value decreases. For example, when using a 1.5 percent sulfur coal, a scrubber which is 50 percent efficient with respect to sulfur oxide removal will satisfactorily meet current emission standards for a coal which contains 13,100 Btu's per pound or more. This efficiency may not be enough if the coal is rated at less than 12,500 Btu's per pound. A 65 percent scrubber efficiency is appropriate when burning a

2 percent sulfur coal, and an 85 percent sulfur oxide removal efficiency is sufficient when burning 4 percent sulfur coal. Since the average sulfur content of coal used in power plants is about 2.5 percent, about 75 percent efficiency is necessary to insure compliance with current EPA new source emission standards. Ninety percent efficiency or better is adequate to comply with the emission standards when using coal up to 5 percent sulfur content. Therefore, all processes which are reported to have a sulfur dioxide removal capability of greater than 90 percent can be used when burning high sulfur high Btu coal.(56)

One of the major obstacles to the use of stack gas scrubbers is their asserted lack of reliability. It is desirable that this be put into some perspective. Louis H. Roddis, Jr., President of Consolidated Edison of New York has said, "... most, if not all, of the economic studies that led utilities to go nuclear were based on assumed energy deliverability of 80 percent or more." He pointed out, however, that as of October 1, 1972, the average energy delivery or availability of the 18 reactors that were operating in the United States was only 60.9 percent. He noted that the problem was that they break down and are too difficult to repair. They are much more costly and time consuming to repair than fossil fuel plants.(57) Obviously, these atomic reactors were all relatively new at the time of Mr. Roddis' statement. However, like new fossil fuel steam electric plants they are used for base load rather than for peaking capacity. The average availability for power generation of coal plants, is also about 60 percent. However, this includes older plants which are on stand-by or peak load only status. A new fossil fuel steam electric plant is expected to be in the 80 percent plus availability category. If it is assumed that new steam electric plants have an 80 percent availability and that atomic plants have a 60 percent availability, a combination of fossil fuel steam electric plants and their necessary stack gas scrubbers would require that the stack gas scrubber have an availability of no more than 75 percent in order that the joint probability equal the 60 percent availability factor apparently acceptable to the public utility industry with respect to new atomic energy plants. It may, of course, be safely assumed that the availability of both scrubbers and nuclear power plants will increase in the future.

C. Use of Western Coal

Stack gas scrubbing, coal gasification and coal liquefication all tend to reduce the dependence of the electric utility industry on the derated estimates of low sulfur recoverable reserves of western coal. In fact, stack gas scrubbing is more efficient if the coal is high rather than low sulfur and if the ash content is relatively low. This tends to eliminate western "low sulfur" lignite and subbituminous coals. There is therefore, less need for stripmining or coal development in the Rocky Mountain region. The processes listed above, however, are expensive. Nevertheless, if western coal is considered an alternative to these processes for electric power generation in the Interior and Appalachian regions, it is possible to make at least a ball park estimate of the amount of money that would be abailable for gasification, liquefication or scrubbing in order to be able to use local coals in the high sulfur categories.

Recently, Detroit Edison made a committment of twenty-six years duration for the purchase of low sulfur low ash coal to be sent to an existing plant in St. Clare, Michigan, and to a new plant in that region which will be ready by 1980. The contract calls for a total coal shipment of over 180 million tons; approaching 4 million tons per year in 1976 and rising to 7 million tons per year for the period from 1981 to 2002. The value of the contract accurding to the seller is approximately $750 million. According to the buyer, the value of the contract for the twenty-six years is $1 billion for the coal, plus $2 billion more for transport and storage.(58) It is this $2 billion which, over a twenty-six year period, must be considered available for alternate uses; in particular, for the purchase of liquefied or gasified coal from Midwest and Appalachian sources or stack gas desulfurization. While it has been noted above that gasification and liquefication involve an energy loss due to processing, it should also be noted that the transportation cost for coal from Montana or Wyoming to Michigan involves an energy cost of 3-5 percent of the heat value of the coal involved. Risser reports that a 7 million ton coal contract, involving rail transport from Wyoming to Chicago, would require 750,000 barrels of diesel oil per year.(59) This cost is paid for, not in terms of relatively abundant coal, but in terms of diesel fuel oil.

FOOTNOTES

(1) The following discussion is based on: National Petroleum Council, U. S. Energy Outlook, Coal Availability, Coal Task Group, 1973, pp. 20-24 including figures 3, 7, 8, 9.

(2) P. K. Theobald et al, Energy Resources of the United States, U. S. Geological Survey, Circular 650, 1972, Figure 2, p. 3.

(3) Bureau of Mines, "Coal-Bituminous and Lignite in 1971," Mineral Industry Surveys, September 27, 1972, Table 2, p. 8.

(4) Department of the Interior, United States Energy Fact Sheets by States and Regions, February 1973, passim.

(5) L. Hoffman, Survey of Coal Availabilities by Sulfur Content, Report to the Environmental Protection Agency, The Mitre Corporation, MTR-6086, May 1972, p. 22, Table XVI.

(6) H. E. Risser, The U. S. Energy Dilemma: The Gap Between Today's Requirements and Tomorrow's Potential, Illinois State Geological Survey, Environmental Geology Notes, No. 64, July 1973, p. 39.

(7) Clean Air Act (42 U.S.C. 1857 et segu.) as amended by the Air Quality Act of 1967 (PL 90-148) and by the Clean Air Act Ammendments of 1970 (PL 91-604).

(8) National Petroleum Council, Op. Cit., p. 51.

(9) Ibid., p. 209.

(10) The point is obvious and can be seen from any of several nomographs such as Figure 2 in R. M. Jimeson, and A. Gakner, "The Demand for Air Pollution Control in the Power Industry," Paper No. 27a, 71 National Meeting, American Institute of Chemical Engineers, February 20-23, 1972.

(11) J. A. DeCarlo et al, Sulfur Content of the United States Coals, Bureau of Mines, IC8312, 1966, Table A-1, p. 19.

(12) Ibid., p. 2.

(13) See Department of Interior, Bureau of Mines, Technology and Use of Lignite, Proceedings, Bureau of Mines-University of North Dakota, Symposium, Grand Forks, North Dakota. May 1-2, 1969 (IC8471), published 1970, and Symposium, May 12-13, 1971 (IC8543), published 1972.

(14) A. Kaufman, "Anthracite as a Utility Fuel," OER Report No. VI, (mimeo), Office of Economic Research, State of New York, Public

Service Commission, August 2, 1971.

(15) It should be noted that for computational purposes the sulfur content category, ≤ 0.7 percent, was assumed to be the point estimate, 0.65 percent. See Table 5.

(16) Department of the Interior, United States Energy Fact Sheets, 1971, February 1973, p. 4.

(17) Bureau of Mines, Op. Cit., p. 9.

(18) The basic data on sulfur reduction are derived from A. W. Duerbrouck, Sulfur Reduction Potential of the Coals of the United States, Bureau of Mines (RI7633), 1972, pp. 233, 265, 269, and 283.

(19) See also: R. J. Helfinstine, et al, Sulfur Reduction of Illinois Coals--Washability Studies, part 1., Illinois State Geological Survey, Circular 462, 1971.

(20) Bureau of Mines, Analyses of Tipple and Delivered Samples of Coal, Collected During Fiscal Year 1972, RI 7346, 1970.

J. B. Janus and B. S. Shirley, Analyses of Tipple and Delivered Samples of Coal, Collected During Fiscal Year 1972, Bureau of Mines RI7712, 1973.

(21) L. Hoffman, Op. Cit., Table XLVII, p. 108.

(22) Bureau of Mines, "Coal-Bituminous and Lignite in 1971," Mineral Industry Surveys, September 27, 1972, Table 42, p. 63.

(23) The lignite total in Table 9 is incomplete as it includes only North Dakota and Montana.

(24) National Coal Association, World Coal Trade, 1971 ed., p. 30.

(25) Idem.

(26) L. Hoffman, et al, Op. Cit., p. 28.

(27) If 1970 is taken as year 1, the expansion factors are 1.4026 (1975), 1.9673 (1980), and 2.7593 (1985).

(28) The expansion factors are 7.1533 (1975), 15.7842 (1980) and 27.8898 (1985).

(29) National Petroleum Council, Op. Cit., p. 4, and Table 1, p. 8.

(30) H. E. Risser, Op. Cit., pp. 11-12 and figure 8.

(31) Business Week, November 17, 1973, pp. 64-65.

(32) National Petroleum Council, Op. Cit., p. 50.

(33) H. E. Risser, Op. Cit., p. 11.

(34) National Coal Association, Bituminous Coal Data, 1971 edition, p. 14.

(35) National Petroleum Council, Op. Cit., p. 4.

(36) Ibid., Table 9, p. 24.

(37) P. K. Theobald, et al, Op. Cit., pp. 3-4.

(38) Bureau of Mines, "Coal-Bituminous and Lignite in 1971," Mineral Industry Surveys, September 27, 1972, p. 7.

(39) National Coal Association, Bituminous Coal Data, p. 75.

(40) Platts Oilgram Price Serve, August 31, 1973.

(41) Department of the Interior, Minerals Yearbook, Vol. 1, 1970, p. 384.

(42) National Coal Association, World Coal Trade, 1971 ed., p. 22.

(43) Ibid., pp. 10, 14.

(44) Ibid., p. 30.

(45) National Petroleum Council, Op. Cit., Table E-1, p. 89 and Table F-1, p. 105.

(46) Ibid., Table 5, p. 13.

(47) A. Crampton, et al, Energy Costs of Limiting the Degradation of the Environment, Physics Department, University of Michigan, Report to the Energy Policy Project, Ford Foundation, June 26, 1973, p. 3-30.

(48) Idem., The thermal efficiency may be defined as the heating value of the methane product and other gases divided by the heating value of the feedstock. Thus, the thermal efficiency is intended to include not only the amount of methane but other thermal considerations such as the vaporization of water and oxygen separation.

(49) National Petroleum Council, Op. Cit., pp. 17, 55-60, and Table 34, p. 68.

(50) Ibid., p. 70.

(51) Ibid., p. 73.

(52) New York Times, November 16, 1973, p. 20.

(53) National Petroleum Council, Op. Cit., pp. 9 and 73.

(54) In its recent study, U. S. Energy Outlook, Coal Availability, released in October 1973, the Coal Task Group of the National Petroleum Council bases its report of the inadequacy of stack gas scrubbing and the technological lag in the area on two studies: first, the four volume 1970 National Power Survey by the Federal Power Commission; second, a study by the National Academy of Science/ National Academy of Engineering, Abatement of Sulfur Oxide Emissions from Stationary Sources, (1970). While both of these sources are,

of course, unimpeachable, they are both considerably out of date for a 1973 publication. The result of using them is misleading.

(55) A. Crampton, Op. Cit., pp. 3-15.

(56) C. R. Aleta, A Critique of the New EPA Emission Standards for New Stationary Sources, Cornell Energy Project, Center for Environmental Quality Management, Cornell University, October 1971, paper No. 71-11, p. 4.

(57) New York Times, November 19, 1972.

(58) Wall Street Journal, August 15, 1973.

(59) H. E. Risser, Op. Cit., p. 43.

BIBLIOGRAPHIC DATA SHEET	1. Report No. UIUC-CAC-DN-73-88	2.	3. Recipient's Accession No.
4. Title and Subtitle LOW SULFUR COAL: A REVISION OF RESERVE AND SUPPLY ESTIMATES			5. Report Date November, 1973 6.
7. Author(s) Michael Rieber			8. Performing Organization Rept. No. CAC-88
9. Performing Organization Name and Address Center for Advanced Computation University of Illinois at Urbana-Champaign Urbana, Illinois 61801			10. Project/Task/Work Unit No. 11. Contract/Grant No. NSF GI-35821
12. Sponsoring Organization Name and Address National Science Foundation 1800 G Street, N.W. Washington, D.C. 20301			13. Type of Report & Period Covered Research, Final 14.
15. Supplementary Notes			

16. Abstracts Conventionally, the definition of low sulfur coal, on which traditional reserve and supply estimates are based, depends only on the weight of sulfur in a ton of coal. The Btu content of the coal is not considered. Coal purchases and SO_2 regulations are based on Btu content. A recalculation of reserve estimates of low sulfur coal on a utility average Btu basis reduces traditional U.S. estimates by over 75 percent and Western estimates by almost 85 percent. When calculated on a Btu basis, maximizing low sulfur coal production results in a supply shortage by 1985. The policy implications for an increased dependence on domestic coal include increased cleaning of high sulfur coal and export limitations on low sulfur coal in the short-term. In the mid-term, large capital expenditures in R and D and processes which reduce or eliminate the sulfur content are required. These include stack gas scrubbing, gasification and liquefication. For the consumer, some of these costs can be offset by the elimination of the transportation charge differential between local high sulfur coal and coal from Wyoming, Colorado and Montana.

17. Key Words and Document Analysis. 17a. Descriptors

Low Sulfur Coal - New definition
Low Sulfur Coal - Reserves
Low Sulfur Coal - Resources
Low Sulfur Coal - Production
Coal Washing
End Use Controls
Coal Gasification
Coal Liquefication
Stack Gas Scrubbing
Western Coal

17b. Identifiers/Open-Ended Terms

Coal
Low Sulfur Coal

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
No restriction on distribution. Available from National Technical Information Service. Springfield, Virginia 22151	UNCLASSIFIED	56
	20. Security Class (This Page) UNCLASSIFIED	22. Price